Marine Boundary-Layer and Air-Sea Interaction

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LONG-TERM GOALS

The long-terms goals of the research are to understand and parameterize the physics of air-sea interaction and the marine boundary layer over a wide spectrum of weather and ocean conditions.

OBJECTIVES

We have instrumented and used the CIRPAS Twin Otter aircraft in several projects (JES, RED CARMA I, II, and III & IV) and the Pelican 2 in CBLAST-Low to study the air-sea interaction. Good quality meteorological and turbulence measurements including eddy correlation air-sea interaction fluxes of momentum, heat, water vapor were successfully obtained. However, since most research aircraft do not operate below 33 m (91 m if poor visibility), flux-profile assumptions have to be made to extrapolate the measurements down to the 10 m "canonical" reference height to calculate the mean quantities to be used in the parameterization of the air-sea fluxes. The objective of this effort is to develop a new aircraft-towed instrumented platform that can reach deep in the surface layer (as low as 10 m) and maintain its height for sustained flux measurements runs. The combination of aircraft mobility and range with the new capabilities of the towed platform will constitute a formidable tool for air-sea interaction studies.

APPROACH

The Towed Atmospheric Sampling Platform (TASP) is a new and novel platform based on well established towed-target drone technology. The TASP is a modified target drone 22.8 cm in diameter and 2.13 m long with a hemispherical nose. It can maintain a radar-controlled height above the sea to heights as low as 10 m while the tow plane is safely above. The desired height command is sent to the drone via a radio signal. The TASP has been equipped with a full meteorological and turbulent flux instrumentation suite (similar to that on the tow research aircraft) and flown off Monterey Bay in April 2007. We collaborate with Zivko Aeronautics Inc. and CIRPAS on this project. Zivko is responsible for the design and fabrication of the TASP, its integration into the CIRPAS Twin Otter research aircraft and operation. CIRPAS provides the tow research aircraft and its facility and support. UCI is responsible for the science aspect, the instrumentation, the data system, data analysis and operations as well.

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14. ABSTRACT
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15. SUBJECT TERMS

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WORK COMPLETED

The bulk of our effort in the last year was devoted to the development and testing of the TASP. A complete instrumentation suite for meteorological and turbulent measurements almost identical to that of the Twin Otter has been successfully integrated onto the TASP as illustrated in Fig.1. The main parts are:

1. Five-hole pressure port radome system for three-dimensional winds
2. Goodrich Aerospace 1024EAL total temperature probe
3. LI-COR 2-Hz humidity and CO2
4. Fast humidity fluctuations from a Campbell Scientific Krypton hygrometer
5. Heitronics IR sensor for sea surface infrared temperature
6. Navigation and motion from a Systron-Donner C-MIGITS III inertial/GPS unit
7. Rate gyro with analog output for synchronization to serial CM-III data

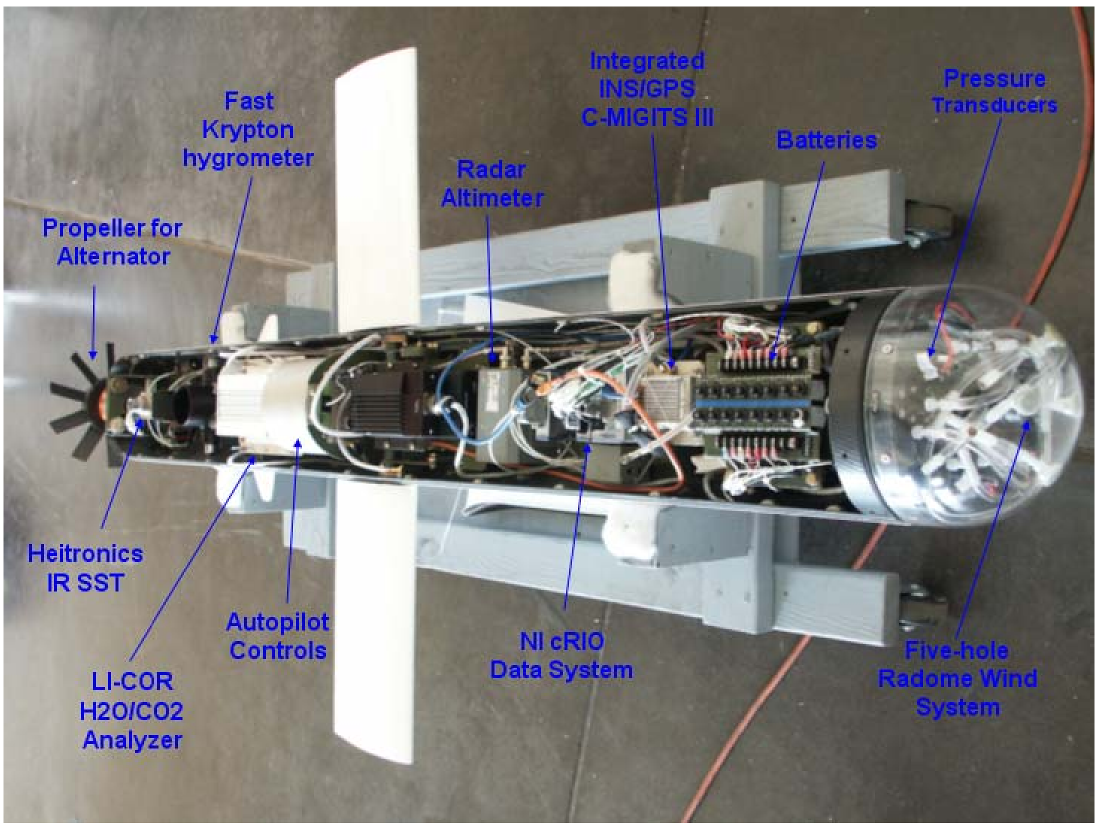

Figure 1: Main instrumentation of the TASP. (The temperature sensor and static pressure ports are located on the bottom half of the TASP body, not shown on this photograph.)

The CompactRIO (cRIO) embedded controller from National Instruments was our choice for the data system because for its small size and weight, its ruggedness and its low power consumption (~7 W). The16 analog channels are digitized at 40-Hz with 16-bit precision and the serial data from the C-MIGITS III are logged at 10-Hz. The analog and serial data are processed by two different processors in the cRIO and to be certain of their synchronization, a high-performance pitch rate sensor with analog outputs was installed. This makes it possible to verify the synchronization and eventually "realign" the data in post-flight processing using a MATLAB-based software package we developed to process the TASP data. The TASP data are saved on the cRIO and transmitted real time to the aircraft computer via a dedicated wireless Ethernet link for real-time monitoring and redundant recording.

With the collaboration of Dr. Arena of OSU (Clearwater, OK), his students and Zivko, we used OSU wind tunnel in February 2007 to calibrate the five-hole radome wind system, determine the position error of the static pressure ports and ensured that the TASP NACA duct draws enough air past the Krypton and LI-COR humidity sensors. We have been collaborating with Cobalt Solutions, LLC (www.cobaltcfd.com) on modeling the flow and pressure fields around the TASP for a variety of airspeed and attack and sideslip angles values using advanced CFD.

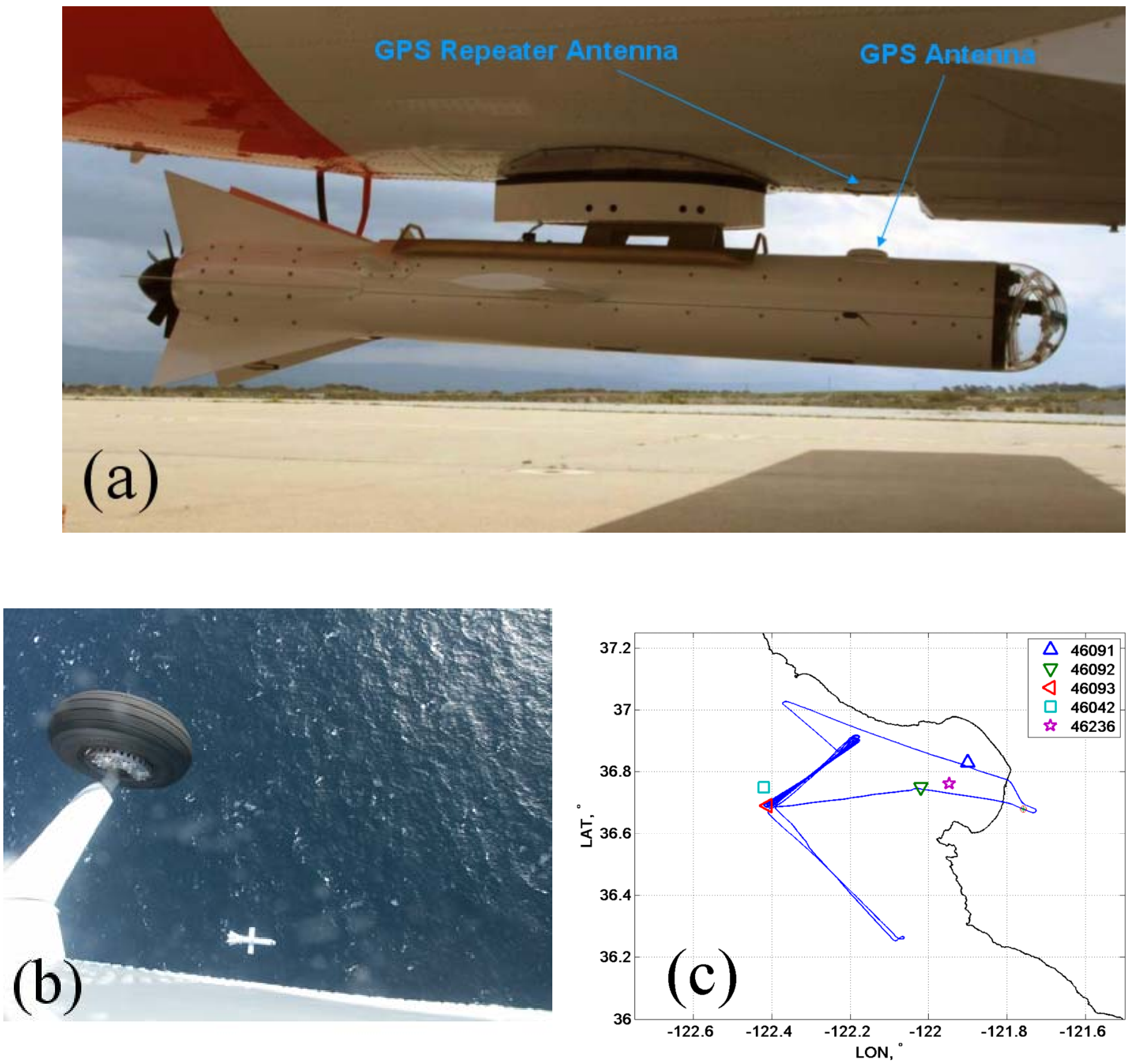

Figure 2: (a) The TASP in docked position beneath its host aircraft, the CIRPAS Twin Otter; (b) TASP being recovered and (c) a typical flight pattern from April 15, 2007 with repeated cross-wind flux legs normal to the shoreline and with the outbound end near MBARI (46093) and NDBC (46042) buoys.

We conducted the first instrumented TASP flight tests in February 2007 off Monterey Bay. The flights helped us identify and correct few major issues. Some of witch were noise in analog channels, interference due to wireless unit transmit power level that needed to be optimized to maximize the transfer rate and minimize interference and determination of the optimal GPS antennas / repeater combo to ensure the TASP C-MIGITS III receives GPS signal at all times even in stowed position (Fig. 2a). After corrections were made to address these problems, a longer field experiment was conducted in April 2007 which comprised 9 flights. The payload on the Twin Otter also included the Doppler wind lidar from Simpson Weather Associates (David Emmit) to obtain wind and aerosol distributions in the marine layer between the Twin Otter tow level and the surface while at the same time the TASP is skimming the surface and collecting turbulence data.

RESULTS

Since the analysis of the April experiment is only in its early stage, the TASP results from the flight of April 15, 2007 we present here are preliminary and the purpose is essentially to asses the performance of the TASP and compare its results to those of the Twin Otter and to two moored buoys (NDBC 46042 and MBARI 46093 identified by their number on the flight track of Fig. 2c). Plots of adjusted pressure altitude from the TASP and the tow aircraft are shown in Fig. 3. During the first part of the flight (before the first ascending sounding), the aircraft flew cross-wind mostly at 33 m for flux measurements. After the TASP was released and commended to go towards the surface, the same flux track was repeated with the TASP mostly at 30 m and the Twin Otter at roughly 304 m (1,000 feet) so that the surface fluxes measurements from the two systems can be compared.

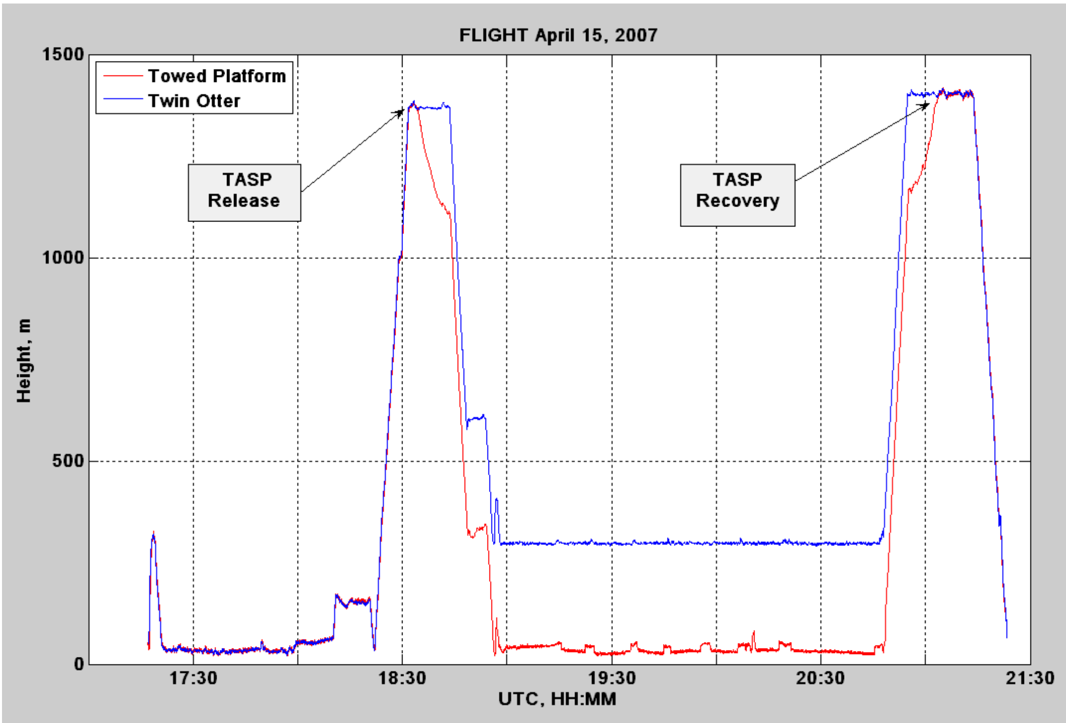

Figure 3: TASP (red) and Twin Otter (blue) heights from adjusted pressure altitude on the flight of April 15, 2007 versus UTC. The first part of the flight (prior to 18:20 UTC) was dedicated to cross-winds low level flux runs with the aircraft.

Data obtained from the 3 soundings are very valuable for comparisons due to the wide range over which the measurements vary. Potential temperature and dew point profiles (arranged from left to right in chronological order of the soundings) are shown in Fig. 4. The left-most sounding is with the TASP in stowed position collecting co-located and simultaneous measurements to those of the Twin Otter. It shows reasonable agreement between the scalars which seem not affected by the expected flow distortions around the stowed TASP due primarily to the wake of the non-retractable nose landing-gear. On the second sounding, the aircraft leveled for a while and turned to reverse course so it is not a typical "close formation" sounding like it was the case on the 3rd sounding where the aircraft ascended straight up at constant heading which explains the better agreement in the latter case.

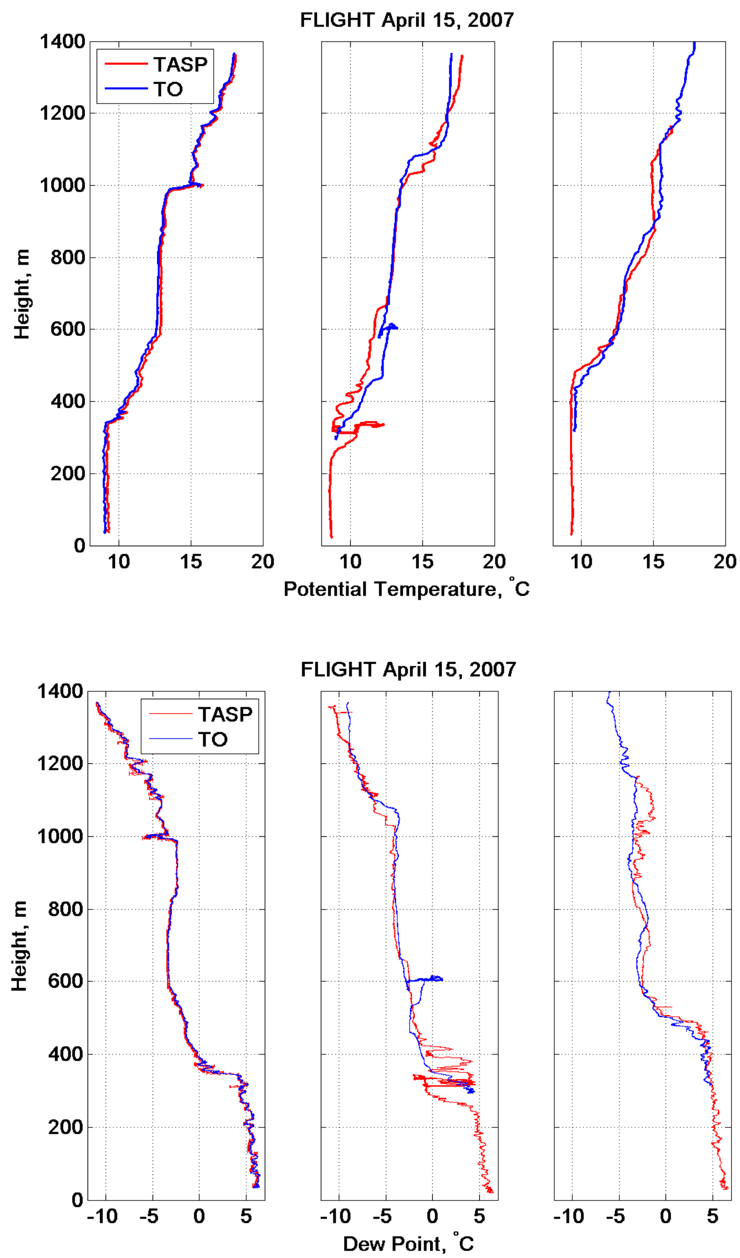

Figure 4: TASP (red) and Twin Otter (blue) profiles of potential temperature (top) and dew point (bottom) obtained from the 3 soundings ending at 18:35 (left), 18:56 (center) and 20:55 (right) (see Fig.2). Data are low-pass filtered at 0.25 Hz cutoff frequency for clarity.

Differences between the TASP and the Twin Otter were roughly 0.2-0.3 ^{o}C in potential temperature and less than 0.2 ^{o}C in dew point. The MABL growth from 340 m to 470 m between the 1st and 3rd sounding is observed on both dew point and potential temperature profiles from both platforms.

The wind speed and direction profiles (Fig. 5) show an overall reasonable agreement between the TASP and the aircraft except for the first sounding (stowed TASP) due to the wake of the non-retractable nose landing-gear. The vertical structure seems to be captured by both platforms.

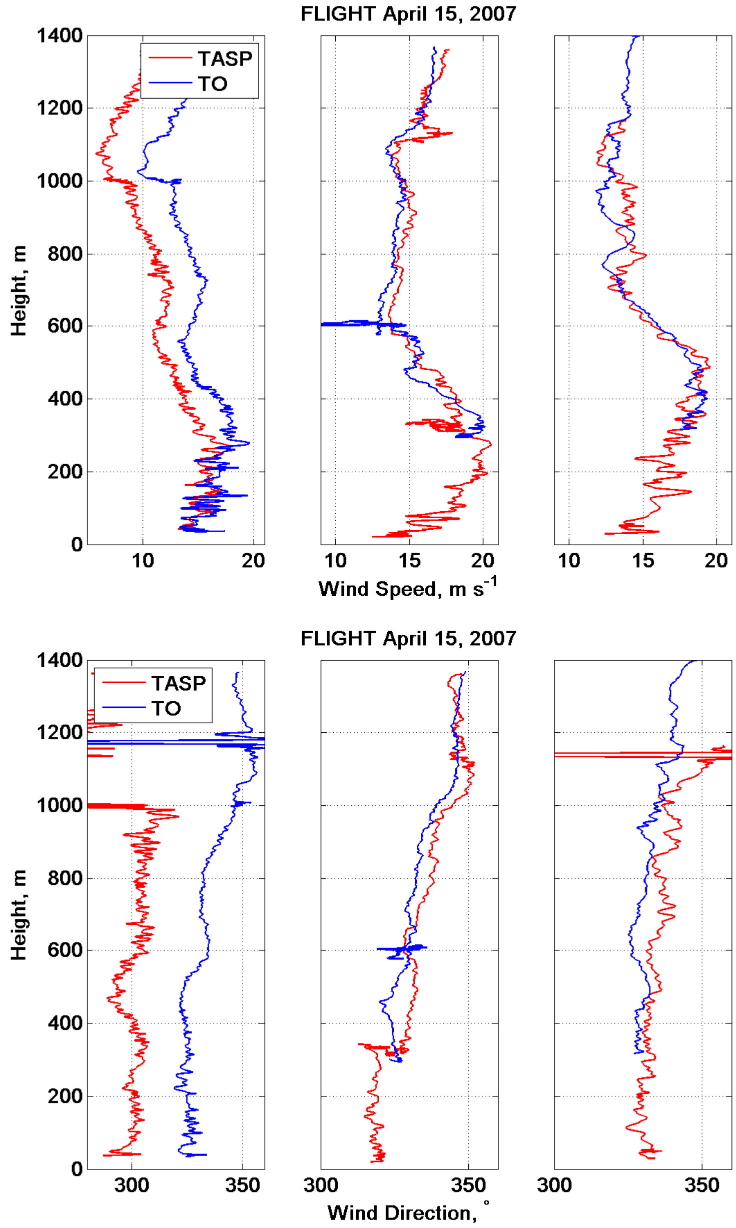

Figure 5: TASP (red) and Twin Otter (blue) profiles of wind speed (top) and direction (bottom) from the 3 soundings ending at 18:35 (left), 18:56 (center) and 20:55 (right) UTC (see Fig. 2). The data were low-pass filtered at 0.25 Hz cutoff frequency for clarity and to reduce the nose wheel wake signature from first sounding data when the TASP was in stowed position.

Eddy correlation fluxes were computed from the TASP and the Twin otter level runs data using the "ogive" method (Friehe, 1991). From spectral analysis, the vertical flux is the integral of the co-spectrum between the vertical velocity and the appropriate variable. The integration is done from high to low frequencies yielding a cumulative integral known as the "ogive". If the sample time series is stationary and long enough, the ogive should exhibit towards the low-end frequencies a smooth convergence towards an asymptotic value which is to be taken as a good estimate of the flux.

Ogives of the along-wind stress component from individual runs of each platform are shown in Fig. 6. There is a reasonable agreement between the TASP and the aircraft for the runs in the 30-33 m elevation range. Towards the higher frequencies, the TASP ogives exhibit irregularities and the reason for this is being investigated using spectral analysis. The power spectra of the three wind components of Fig. 7a show that the TASP vertical wind component has a salient peak at about 0.8 Hz and large decrease in energy at higher frequencies. Power spectra of pitch, yaw and attack angles and of attack and sideslip differential pressures also showed a peak at 0.8 Hz. It could be that, in keeping the set altitude, the autopilot control loop is generating pitching oscillations via the wing that are too fast (0.8 Hz) and with a too large (-4^{o} to $+6^{o}$) amplitude to the effect to cause flow distortions around the nose radome. Another possible explanation is that the integrated 10-Hz INS/GSP "solution" output (velocities and attitude angles) being heavily filtered, may not provide enough bandwidth to completely measure the TASP dynamics. More work is required to fully understand the cause of this problem and correct it.

For comparison, scatter plots of the pitch angle versus yaw fluctuations during the two ~ 30 m flux runs are shown in Fig. 7b for the TASP and the Twin Otter. While the yaw variations are about the same on this cross-wind leg, the aircraft pitch variations are considerably less than those of the TASP.

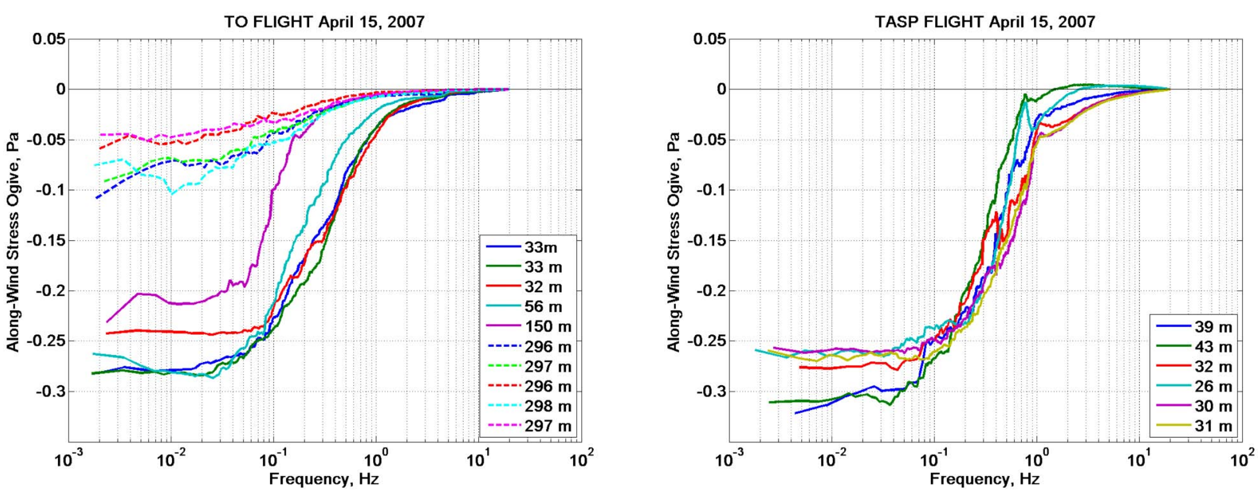

Figure 6: Along wind stress ogives obtained from cross-wind level runs at the indicated elevations of the TASP (left) and the Twin Otter (right). Note that the estimate of the stress component is determined by projecting on the ordinate axis the low frequency "asymptote" value of each ogive.

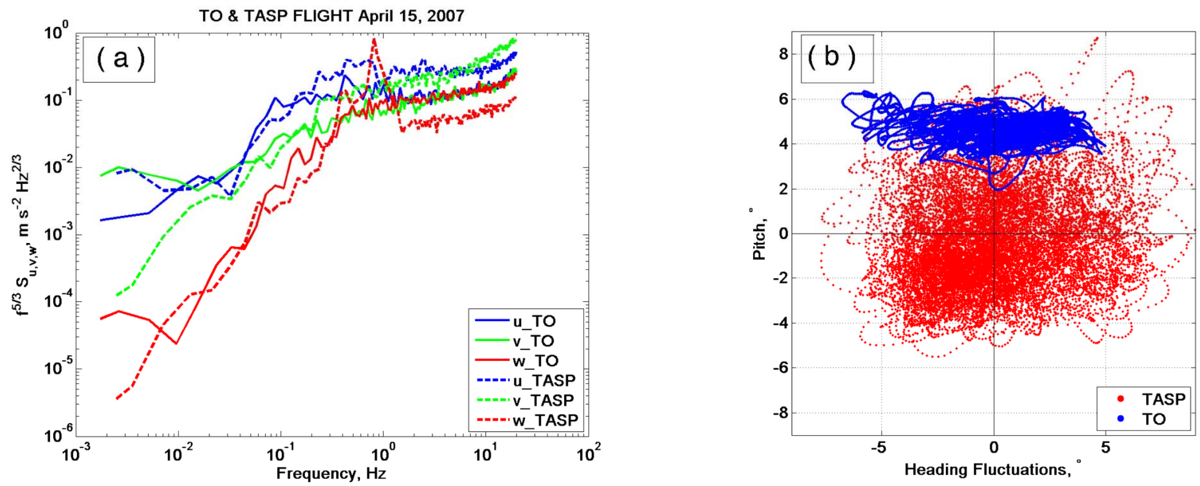

Figure 7: (a) Power Spectra times (frequency)$^{5/3}$ versus frequency of the along-wind (blue), cross-wind (green) and vertical (red) wind components from an aircraft run (solid) and a TASP run (dash) both at ~30 m and over the same cross-wind track; (b) scatter plot of pitch versus variations of yaw about the mean for the TASP (red) and the aircraft (blue) during the same two flux runs (right). Data used are sampled at 40-Hz.

A summary of comparison results between the TASP, the aircraft and two buoys (NDBC 46042 and MBARI 46093) is given in Table 1. The aircraft and TASP data were averaged over 3 cross-wind flux runs that were between 30 and 33 m. The buoy data were averaged over the time it took to complete the 6 TASP and aircraft runs. No height adjustments were made to the ~30 m data, therefore, it is expected that the TASP and Twin Otter data have higher wind speed U and lower pressure, P, and ambient temperature, T_a. This is the case though the Twin Otter P and T_a may be too low. Also, the IR sea surface temperature, T_s, values from the TASP and the aircraft IR pyrometers are expected to be lower than the water temperature measured by the buoys at 0.6 m depth. Values of U and the friction velocity, u_*, from the TASP are greater than those of the Twin Otter but the average values of the drag coefficient $C_D = u_*^2 / U^2$ obtained from the two platforms are almost the same.

Table 1: Averaged TASP and Twin Otter results from 3 cross-wind flux runs at roughly 30 m over the same cross-wind track. Data from NDBC (N46042) and MBARI (M46093) buoys (located at the outbound end of the track) were averaged over the time it took to complete the aircraft runs.

	T_a, °C	T_s, °C	T_d, °C	U, m s^{-1}	W_d, °	P, hPa	u_*,m s^{-1}	1000*C_D
TASP	**10.1**	**9.6**	**6.4**	**14.5**	**322**	**1014.2**	**0.488**	**1.132**
TO	**9.6**	**9.5**	**6.0**	**13.9**	**323**	**1013.1**	**0.468**	**1.133**
N46042	**10.5**	**10.5**	**-**	**13.0**	**325**	**1015.9**	**-**	**-**
M46093	**10.5**	**10.5**	**-**	**12.6**	**320**	**-**	**-**	**-**

The sample TASP data shown indicate that the concept works as evidenced by the reasonable results obtained. As with many new and novel systems, there are some imperfections and technical challenges that need to be understood and corrected. We plan to do that in the near future.

IMPACT/APPLICATIONS

The TASP is a unique platform for the measurement of air-sea fluxes and other variables at low heights over the ocean. The role of the ocean and its interaction with the atmosphere remains an important research area in climate studies, wave physics, trace gas exchange, and hurricanes, for example. Recent operational problems attributed to sea salt contamination in low-flying hurricane research aircraft engines in hurricanes will most likely limit low-level boundary-layer flights. UAS (Unmanned Aerial Systems, previously denoted UAV) and drop sondes are alternates for measurements near the ocean surface. Drop sondes have limited sensor capability, and most present UAS vehicles do not have the payload and power capacity similar to the TASP. The TASP therefore, fills a needed gap between the drop sonde, in situ aircraft, and UAS. Other sensors, such as aerosol, chemical, radiation, etc., could be accommodated in the TASP.

RELATED PROJECT

CARMA: We completed 16 flights of phase IV during the month-long experiment in August, 2007. Conditions varied from zero winds and mirror waters days to days with 20 m s^{-1} and from clear days to stratus days. Santa Barbara fire plumes were also sampled. Dean Hegg of UW is our collaborator.

CBLAST-Low : We are collaborating with Tom Farrar on a case study paper on the cold filament response observed during the 2003 experiment. (http://www.whoi.edu/science/AOPE/dept/CBLAST/lowwind.html).

We are involved in the Gulf Of Tehuantepec Experiment (GOTEX) where we used the NCAR C130 to study the air-sea interaction under strong gap winds conditions. We are in the process of comparing our findings from our ONR-funded JES cold air outbreaks experiment to those of GOTEX. The URL for GOTEX is http://raf.atd.ucar.edu/Projects/GOTEX/docsum.html)

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